



Lecture 10
June 7, 2003

The last lecture

It's about time!

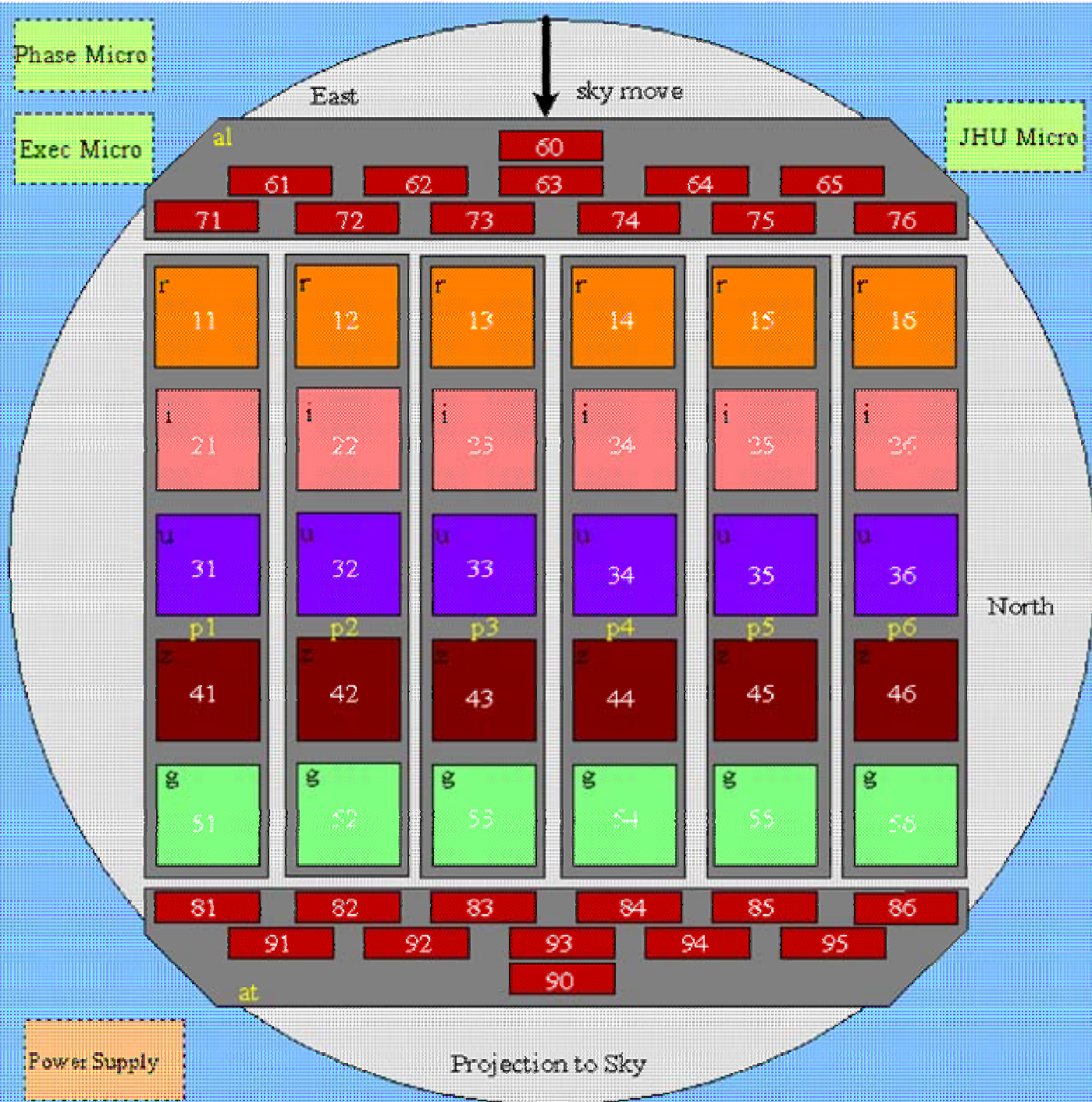
Construct a 2.5m telescope & instruments to

1. image the sky to 23rd mag in 5 colors (10^9 objects)
2. take the spectra of 10^6 objects (mostly extragalactic)

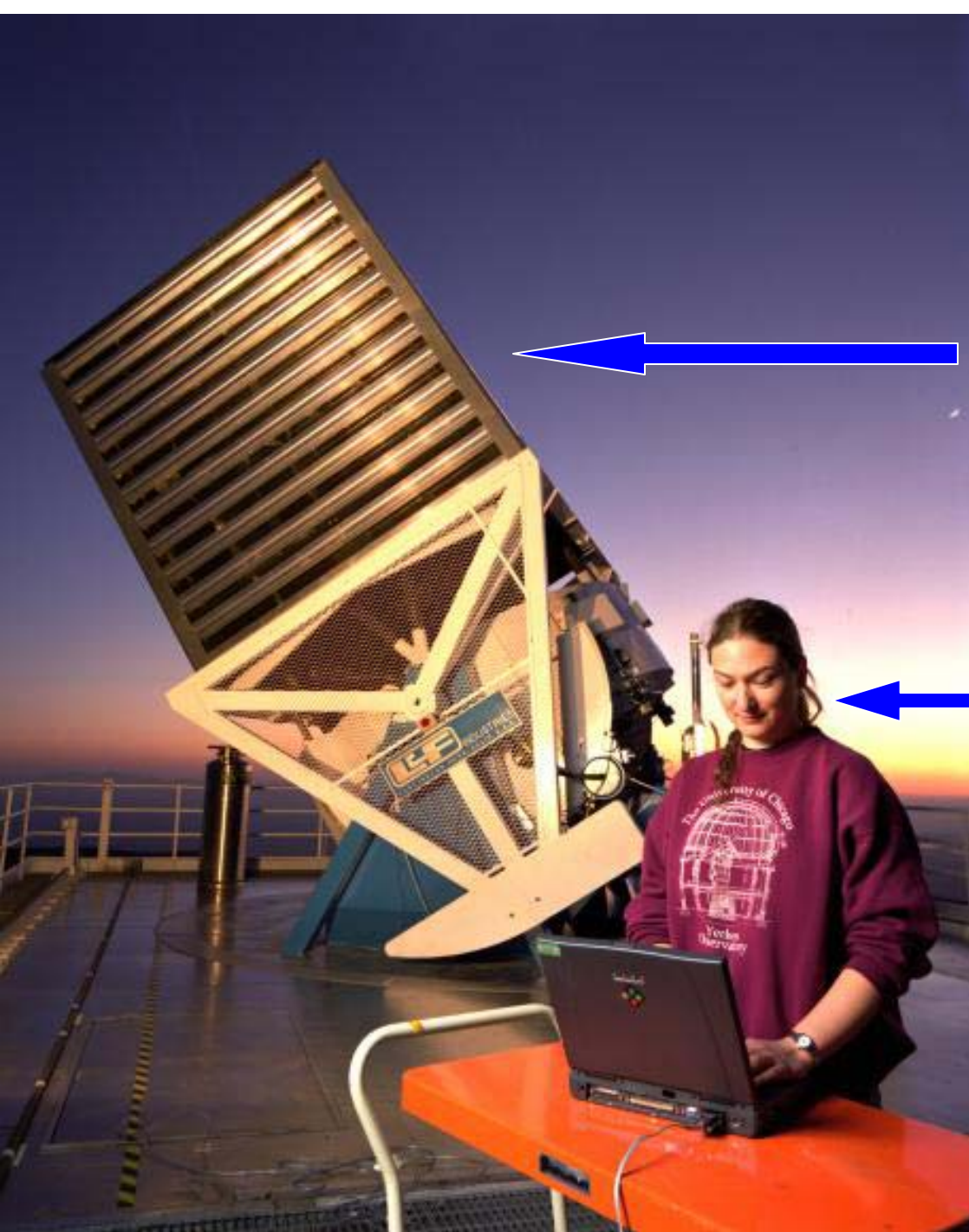




SDSS camera

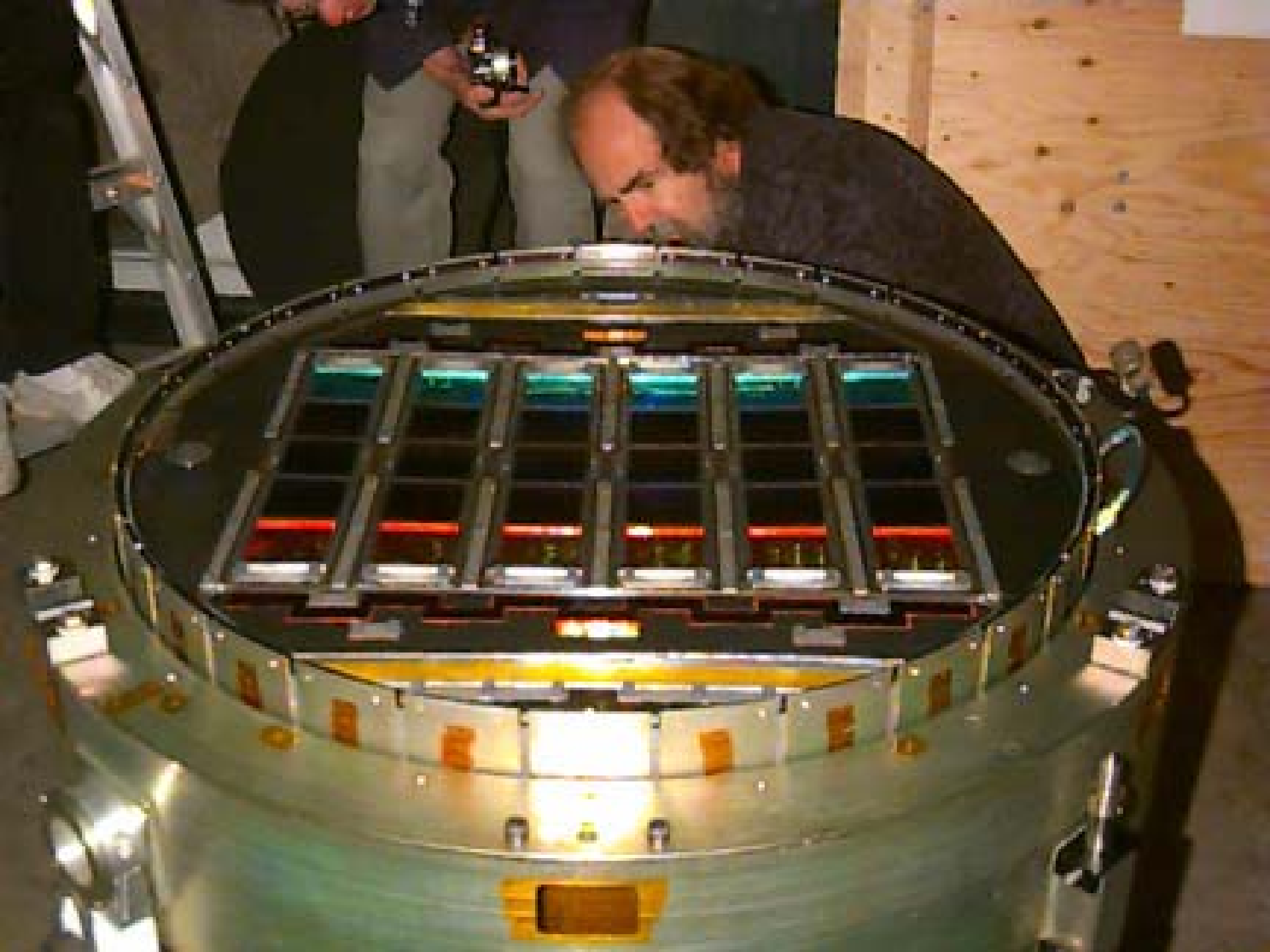


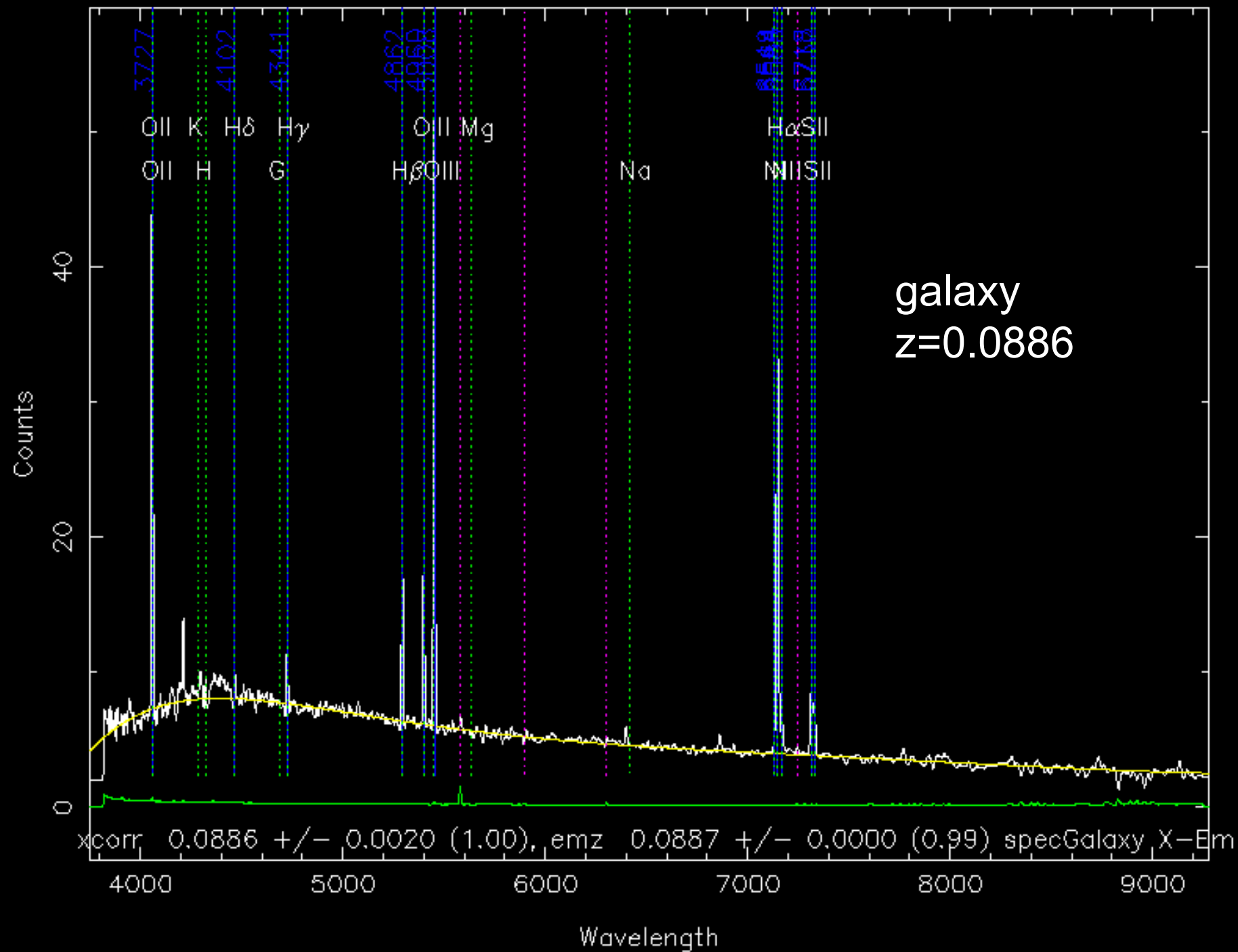
SDSS

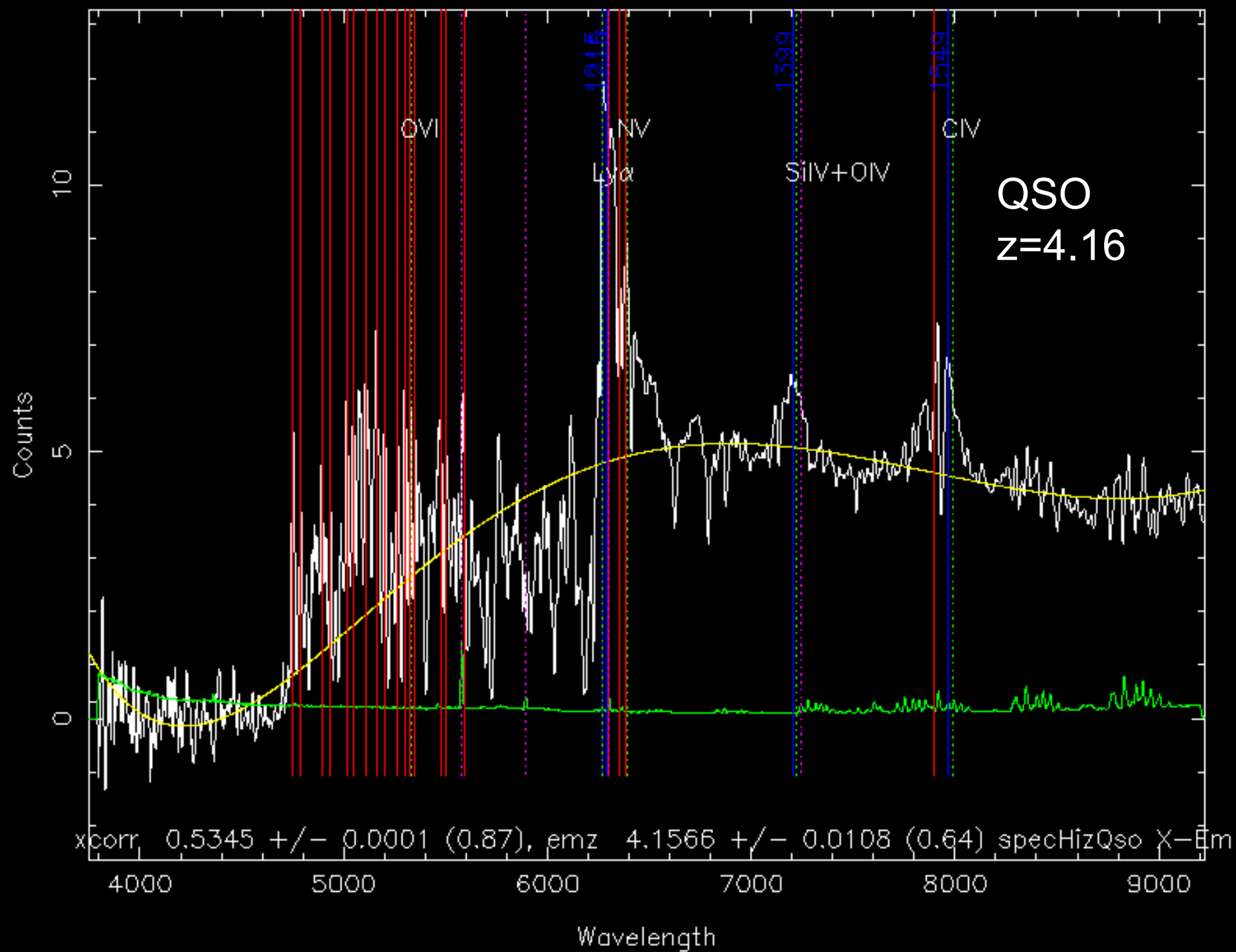


2.5 m telescope

**data acquisition
system**







BEFORE NOTHING ?

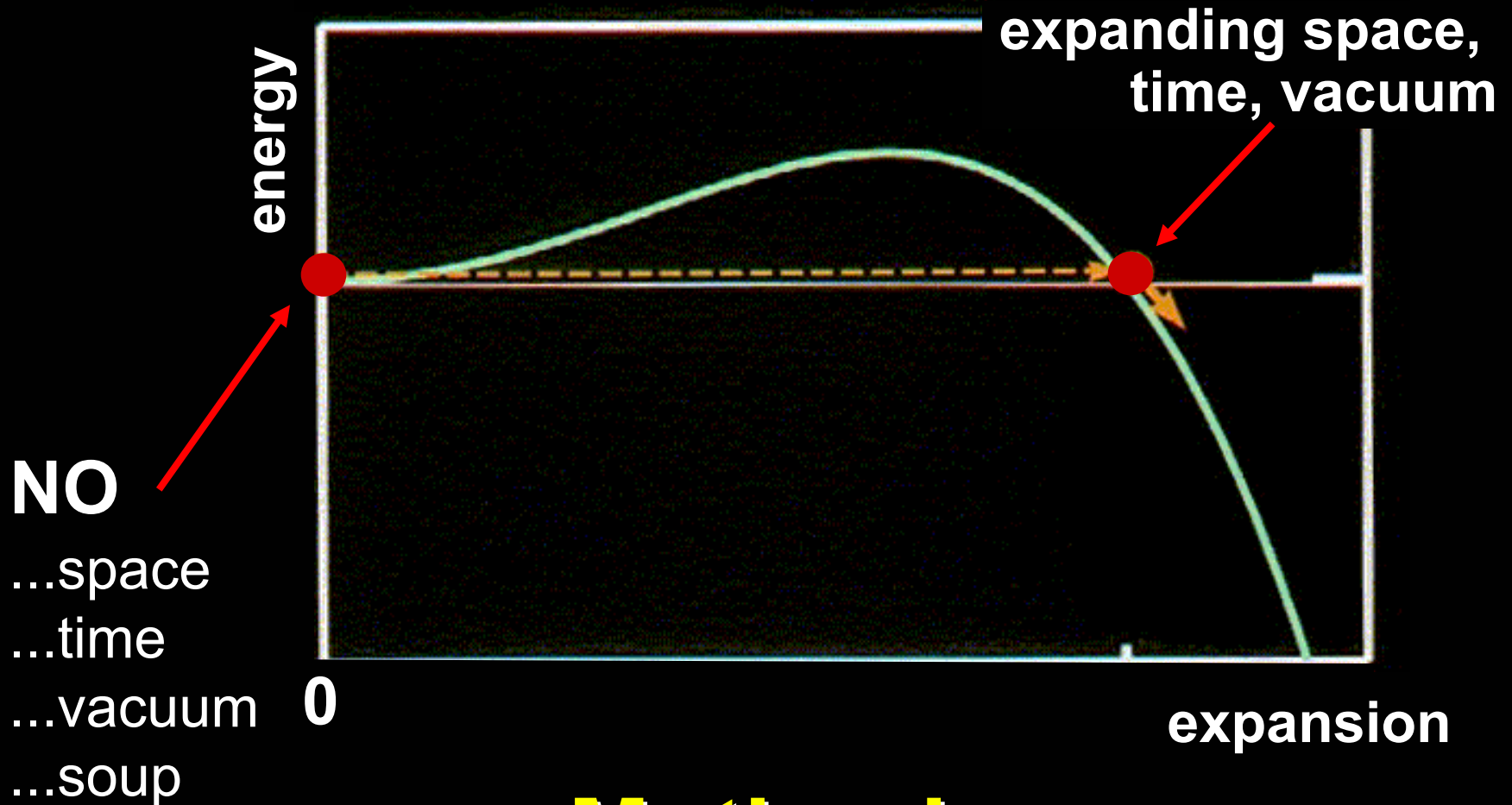
NOTHING HAD A BEGINNING:

- quantum creation of space, time, vacuum *from less than nothing.*
- nothing is unstable -- emergence of the universe is *inevitable.*

NOTHING IS ETERNAL:

- universe is *still inflating.*
- on largest scales, universe is unchanging -- *no beginning and no end.*

QUANTUM TUNNELING



**Motion in
“IMAGINARY TIME”**



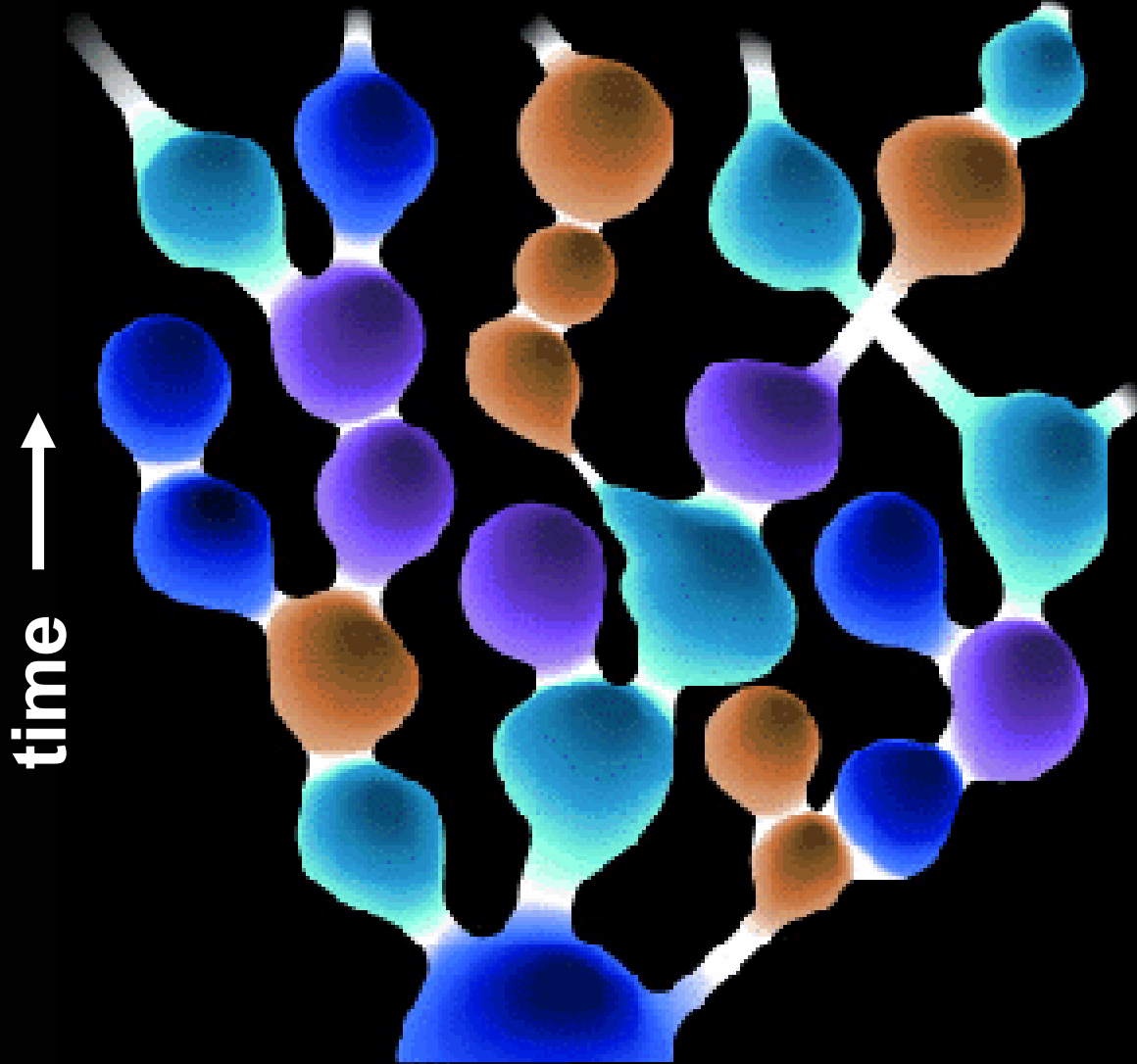
Ludwig Boltzmann

**Born: 20 Feb 1844
Vienna, Austria**

**Died: 5 Oct 1906
Duino (near Trieste),
Austria (now Italy)**

Quantum fluctuations lead to many different bubbles

Eternally self-reproducing universe



Universe has no beginning?....no end

Each bubble grows to cosmological size

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Cosmic Questions:

1. How multidimensional is the universe?

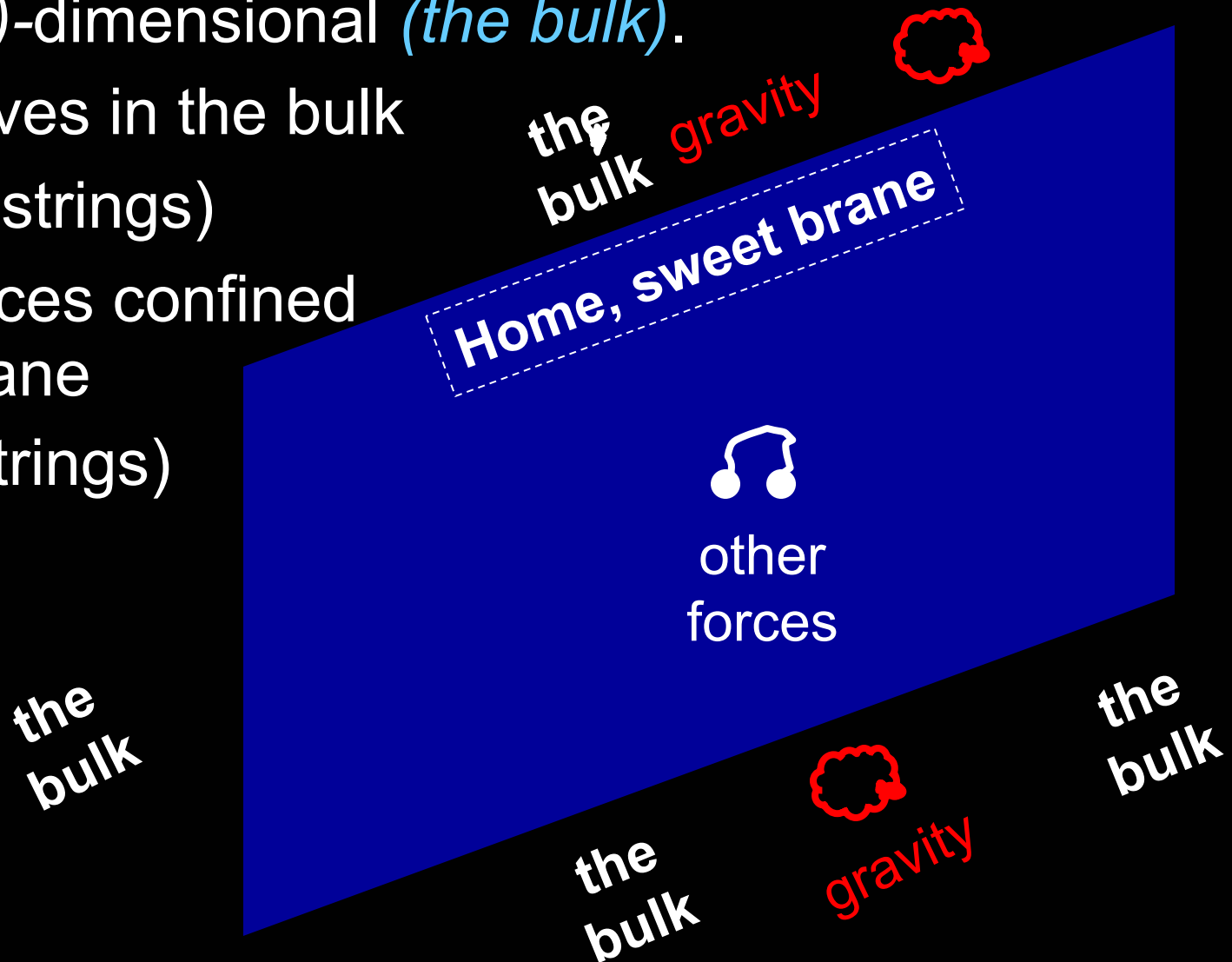
26, 11, 10, 2 dimensions?

The brane world

- Old idea of extra dimensions and unification
Kaluza (1919) Klein (1926)
 - “Compact” extra dimension
 - unify gravitational force & electromagnetic force
- Extra dimensions required in string theory/M-theory
 - $D = 26, 11, \text{ or } 10$
 - What to do with the extra dimensions?
- We live on a $(3+1)$ -dimensional slice (*the brane*) in a $(3+1+n)$ -dimensional space (*the bulk*).

The brane world

- We live on a $(3+1)$ -dimensional slice (*the brane*) in a $(3+1+n)$ -dimensional (*the bulk*).
 - Gravity lives in the bulk (closed strings)
 - Other forces confined to the brane (open strings)

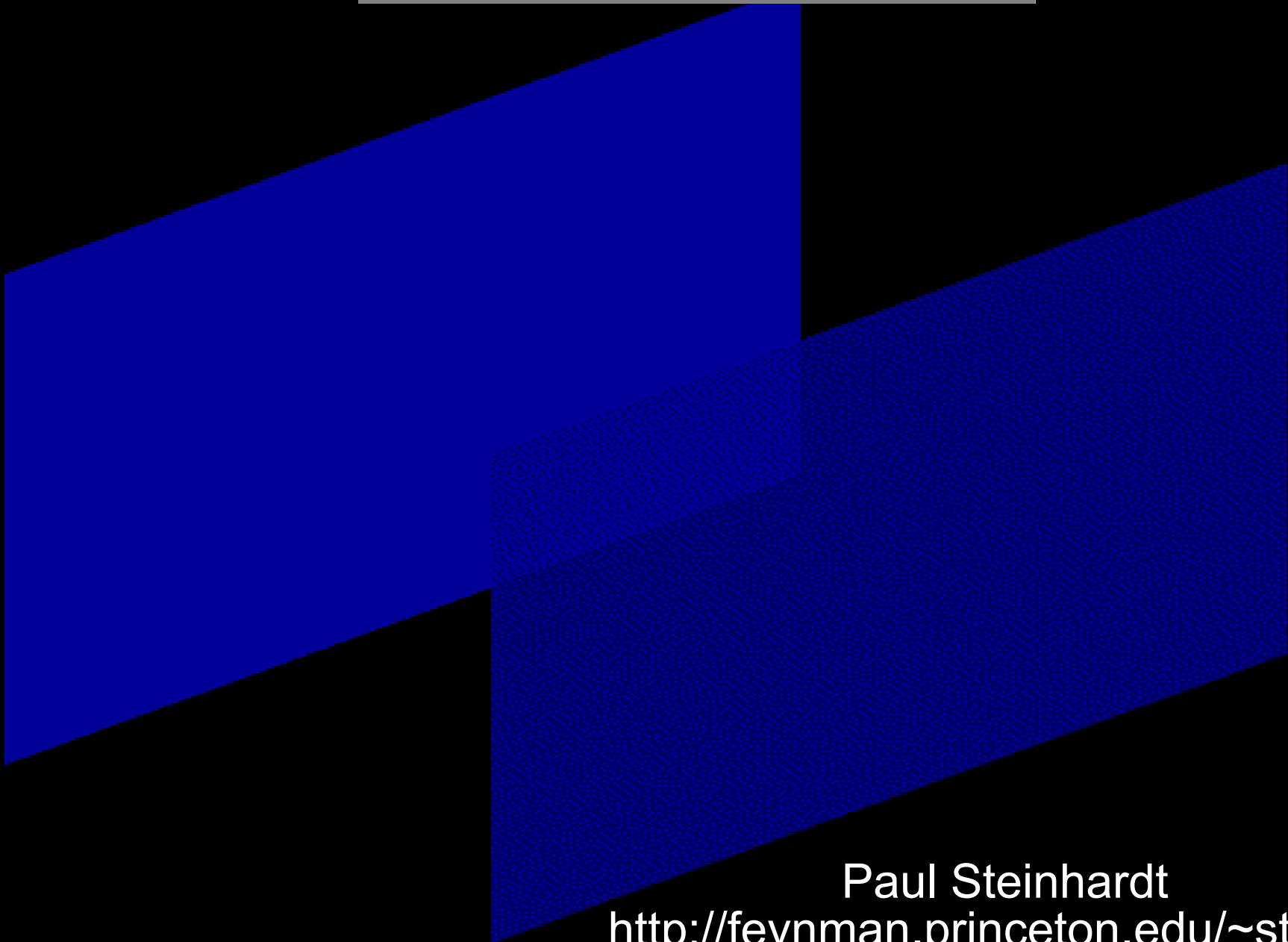


The brane world

Home sweet brane

Klingon brane

The brane world



Paul Steinhardt
<http://feynman.princeton.edu/~steinh/>

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1. How multidimensional is the universe?
2. How did the universe begin?

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Cosmic Questions:

1. How multidimensional is the universe?
2. How did the universe begin?
3. Why does matter fill the universe?

An average cubic meter of the universe today:

400,000,000	photons
1	protons or neutrons
0	antiprotons or antineutrons

Hot and asymmetric universe

An average cubic meter of the early universe:

400,000,000	photons
400,000,000	protons or neutrons
399,999,999	antiprotons or antineutrons

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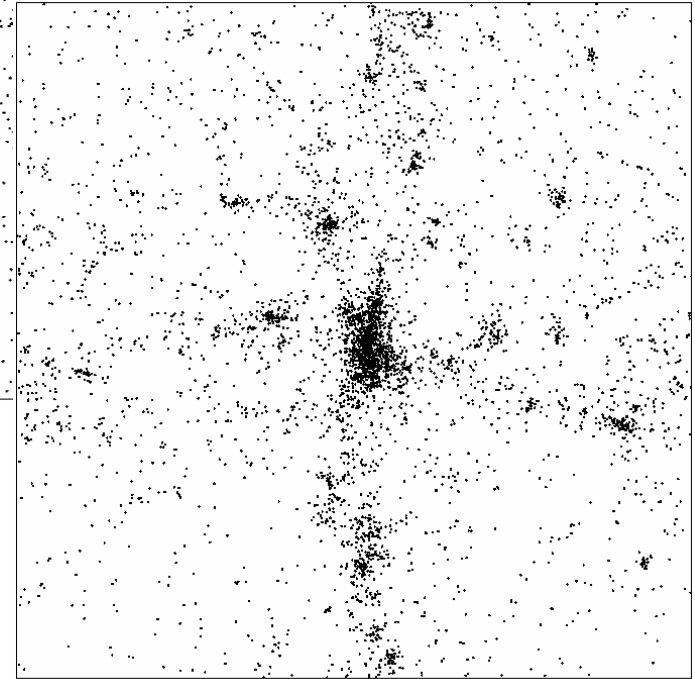
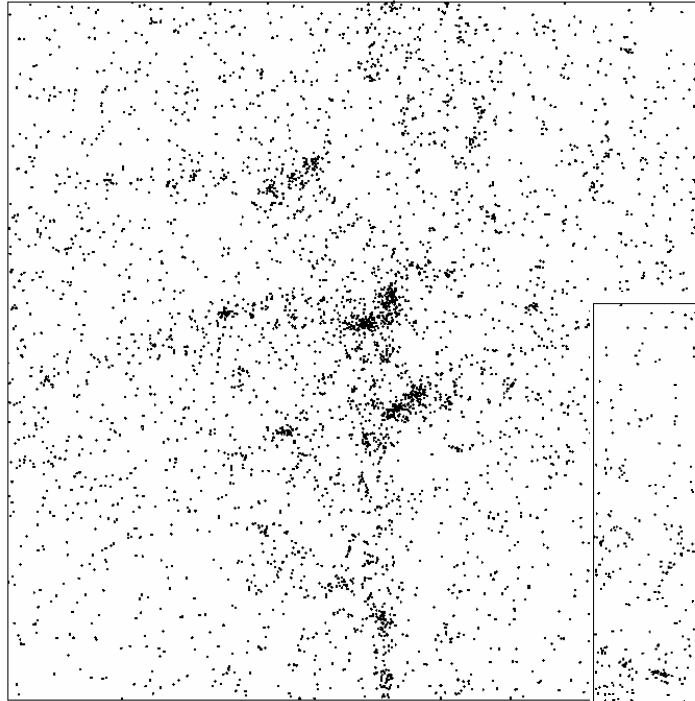
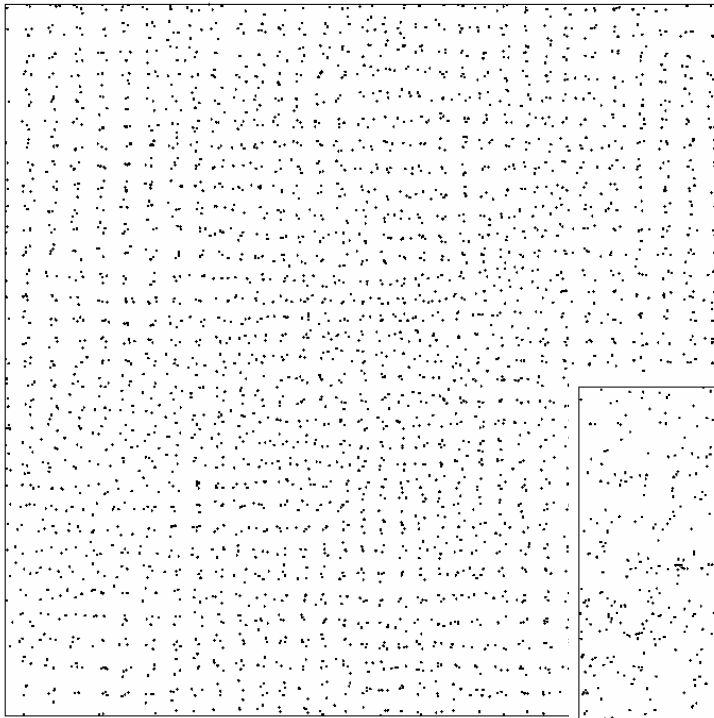
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Cosmic Questions:

1. How multidimensional is the universe?
2. How did the universe begin?
3. Why does matter fill the universe?
4. How did galaxies form?

Seeds of structure



time →

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Cosmic Questions:

1. How multidimensional is the universe?
2. How did the universe begin?
3. Why does matter fill the universe?
4. How did galaxies form?
5. What is cold dark matter?

Most of the universe is dark !

- Modified Newtonian dynamics
- Planets
- Mass disadvantaged stars
 - brown red white
- Black holes
- Fossil remnant of the big bang
- The weight of space

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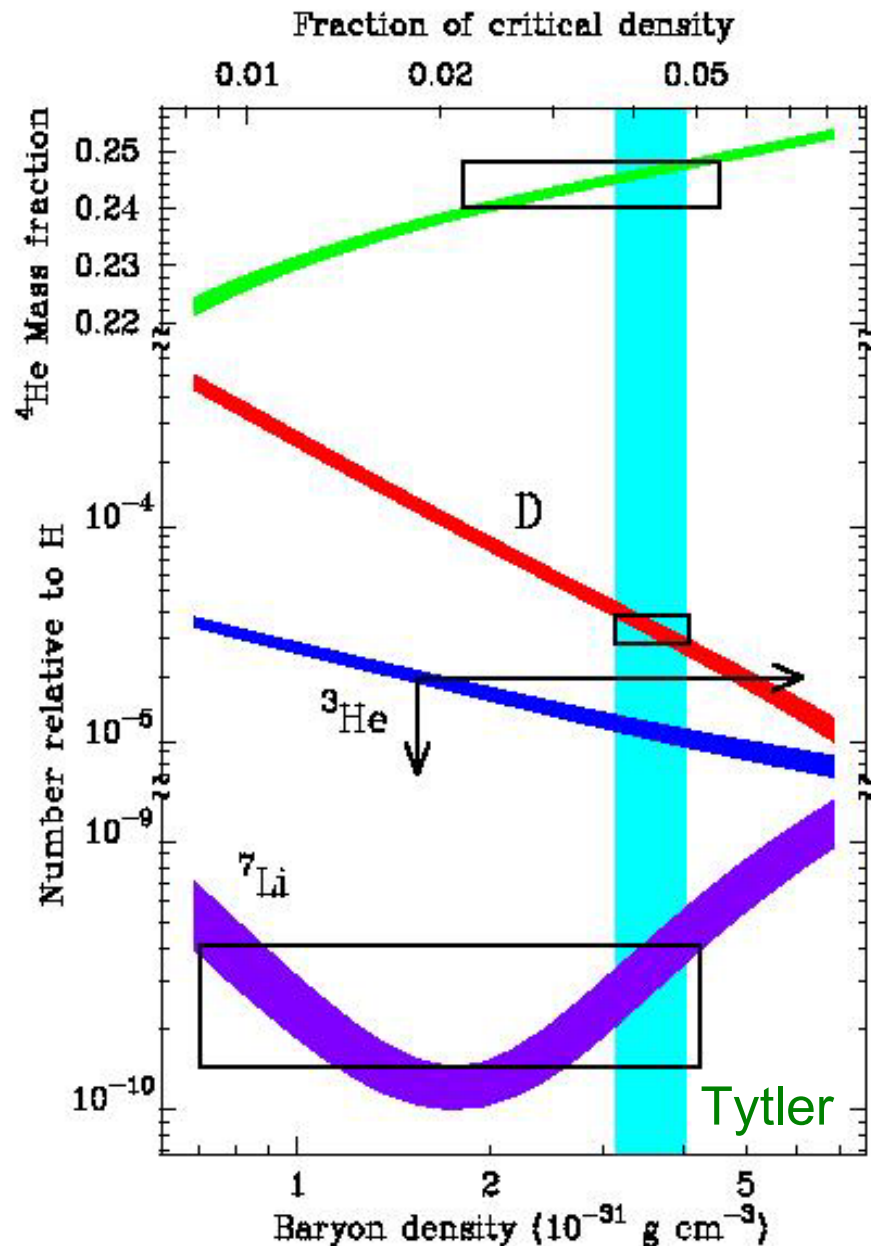


Cosmic Questions:

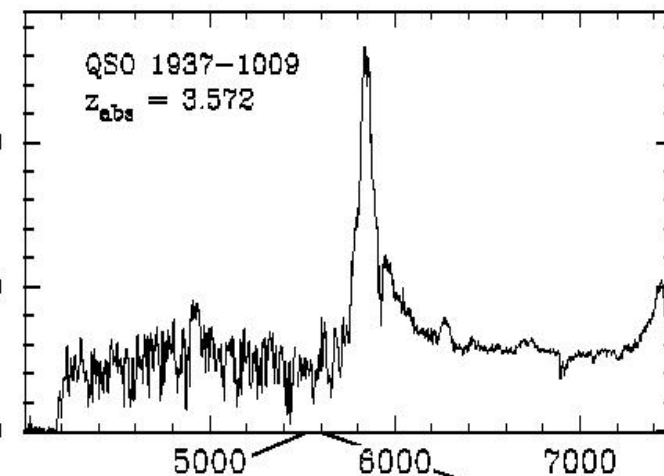
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6. Are all the baryons assembled in galaxies?

Baryons $\Omega_B h^2 \sim 0.02$ QSO 1937-1009

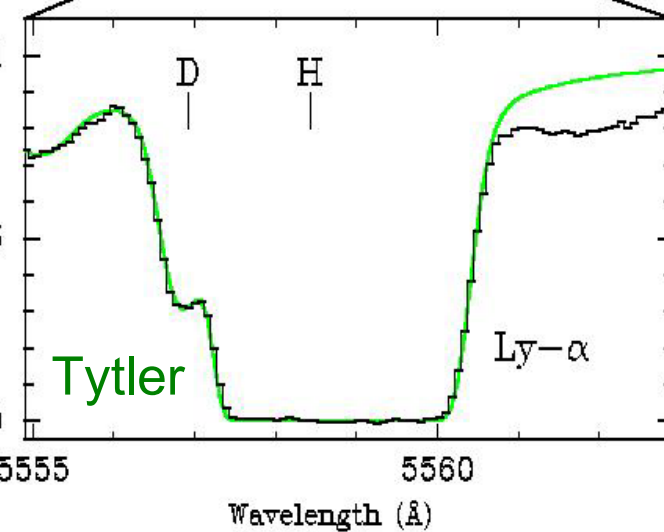
Ly- α



Flux ($10^{-16} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$)



Normalized Flux



Big-bang nucleosynthesis tells us the present baryon density

We only see 10% of that – most of normal matter is dark

**Simulations predict it is in hot (million degrees) gas
between galaxies.**

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7. What is the dark energy?

Energy of the quantum vacuum

Observed:	$\rho \leq 10^{-30}$	g cm^{-3}
Quantum field theory:	$\rho = \infty$	g cm^{-3}
Quantum gravity:	$\rho = 10^{+90}$	g cm^{-3}
Supersymmetry:	$\rho \leq 10^{+30}$	g cm^{-3}
Higgs potential:	$\rho \sim -10^{+25}$	g cm^{-3}
Other sources:	$\rho \sim \pm 10^{+20}$	g cm^{-3}

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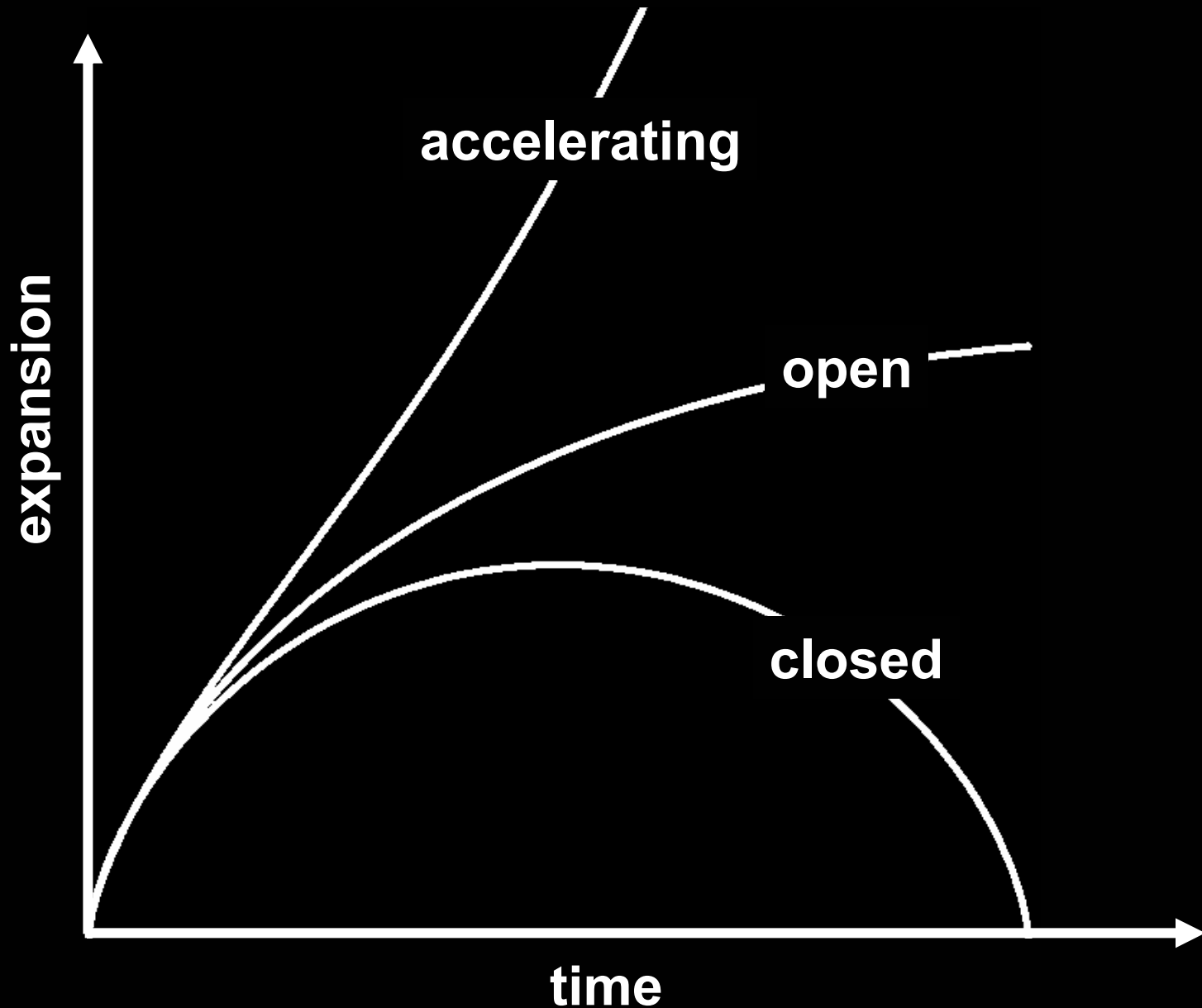
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5. What is cold dark matter?
6. Are all the baryons assembled in galaxies?
7. What is the dark energy?
8. What is the destiny of the universe?

The accelerating universe?



A Brief History of ***a Bunch of Things***

Mass transfer

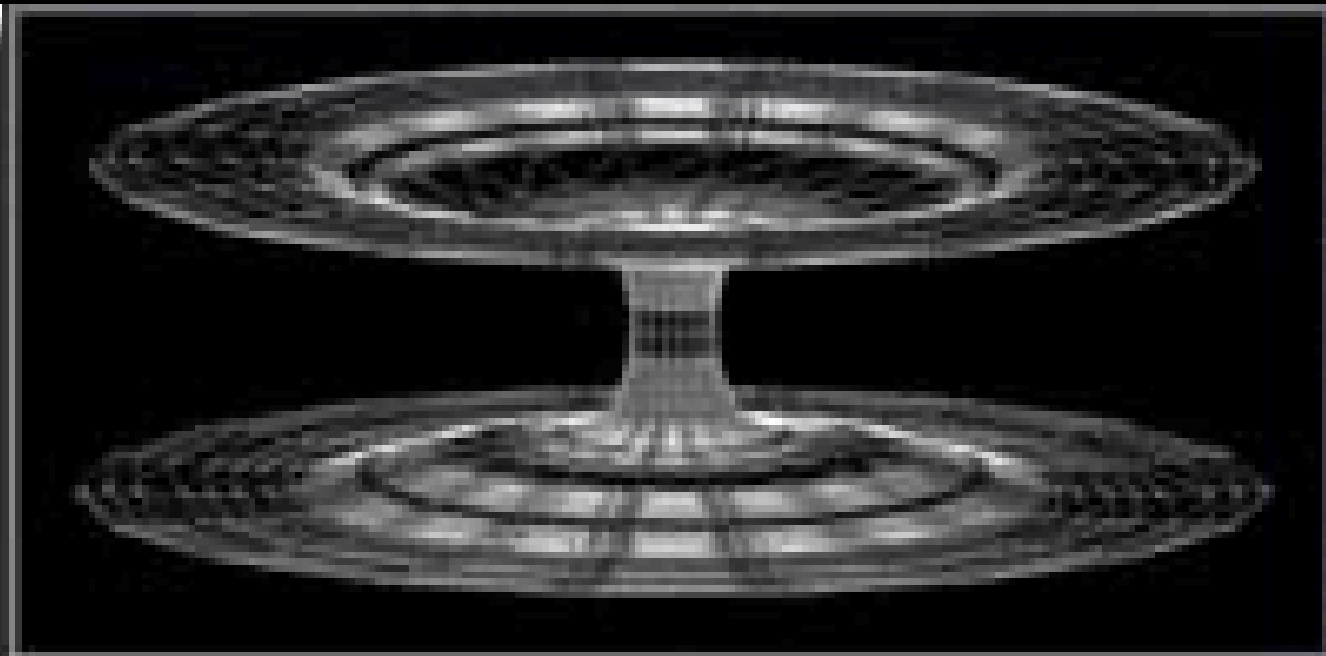
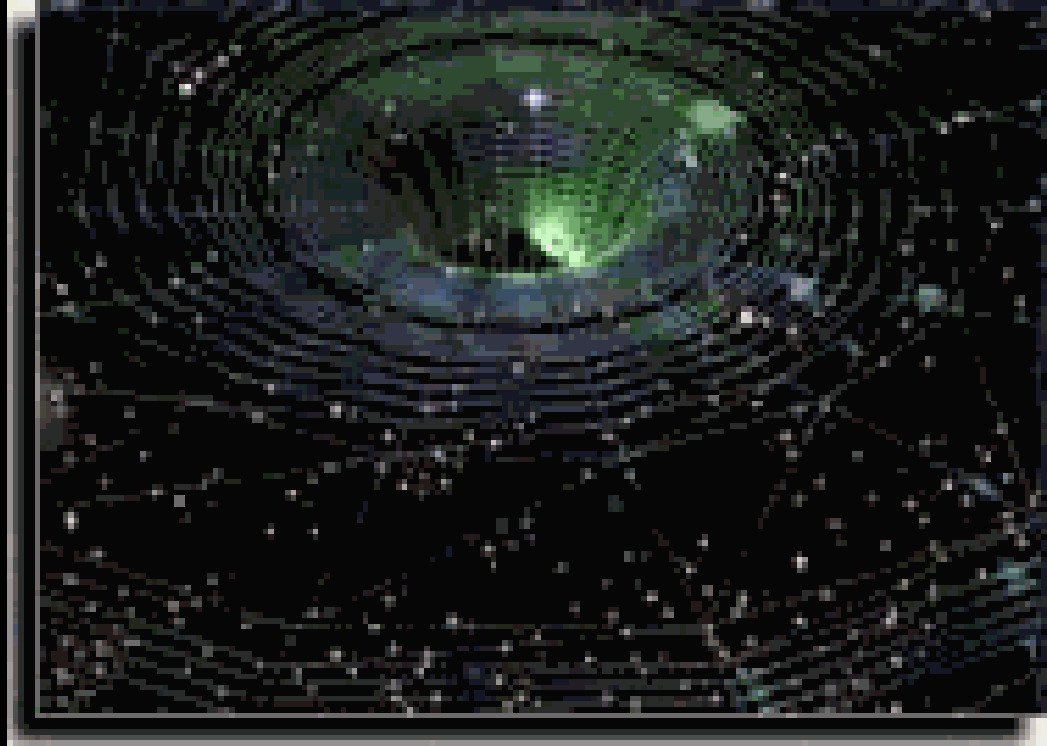


Red shift

Time dilation

Falling into a black hole

wormhole



Naked singularity

Cosmic censorship